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Geological Structure and Geomorphological Aspects in Karstified Susceptibility Mapping of Limestone Formations

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Abstract

Major cavities and underground drainage tend to develop with the aid of massive or thick-bedded and well-jointed limestone whilst porous and soft limestone is more likely to form micro-cavities and localized karst along bedding and close to ground level. This phenomenon wouldprobablybe explained by studying the movement of water circulating through the pores in the limestone. Strong correlations between fracture patterns and drainage lines/cavity zones have been long suspected by many researchers in the past (Mayer, *et al.*, 2003). An assumption has been made that fractures offer lines of decreased hydraulic resistance to groundwater flow and therefore they are more easily exploited by weathering and erosion processes than their adjacent rock (Sower, 1975 and Ericson *et al.*, 2004). The end product of the weathering and erosion process is a river channel or active cavity, developed along fractures orientation. Thus, the karstic surfaces are consistently developed along the joint sets orientated at limestone is strongly fractured with the dominant joint orientations.In this paper, a methodology for karstified susceptibility assessment of three selected limestone formations is presented specifically looking at tectonic history, joint pattern, and topographyand karstification intensity. Structural analysis, based on rose diagram and stereographic equal-angle projection method have been used to analyze the joint orientations.

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1. Introduction

A great numbers of variables that involved in the process of karstification have strongly influenced the character of the developed karstic features; this is demonstrated by the existence of a huge variation of karst from one place to another.As in Waltham and Fookes (2003), a functional combination of climate and historical geology (sedimentation and structural history) broadly influenced the karst classification system, and it must therefore be borne in mind that the level of karst complexity also increases in heavily tectonized rock.

In Waltham and Fookes system, karst formation is classified into five different progressive classes: kI – juvenile karst; kII – youthful karst; kIII – mature karst; kIV – complex karst and kV – extreme karst. Karst kI is the youngest form of karst landscape, often only to be seen in deserts and periglacial zones and considered to show little potential for producing engineering hazard. In contrast, karst kV is the oldest and most hazardous from the engineering point of view, as it exhibits a complex cave system; it is usually encountered in wet tropical regions. In Malaysia, karst in most of limestoneformations are dominated by its highly variable rockhead and is thus classified as extreme karst (kV) under the Waltham and Fookes (2003) system. Karst landscape of kV, i.e. as seen above the ground level, will assist in visualising the true extent of sub- surface karst in parts of Malaysia, otherwise only revealed by borehole cores.

Bedding planes and tectonic structure such as faults, folds and joints, have been frequently linked to the development of karst systems and in some cases, are given as the single most important factor that determines the variety of karst seen today (Waltham *et al.*, 2005). In karst systems, horizontal or vertical cave passages are often developed preferentially within these lines as they are less resistant towards dissolution compared to the adjacent intact rock mass. The bedding plane in a sedimentary rock is a primary structure, originally planar and of low dip, characterised by differences in sediment composition, structure and texture. The variation caused by these changes, developed at deposition, might come in the form of the grain size or mineral content. In contrast, tectonic structuressuch as faults and joints are secondary planes, formed in response to tectonic forces and occur after lithification. In this study, the effect of parameters cited towards the intensity of karstification were based on field data mapped from three different sites, the SMART tunnel site of the Kuala Lumpur Limestone Formation, limestone quarries in Kinta Valley, Perak and Kangar, Perlis for both the Kinta Limestone Formation and the Chuping Limestone Formation.

2. Methodology

Detailed geological mapping were carried out at three localities of rock formation. In this exercise, detailed measurement of the orientations (orientation of strike and angle of dip) of bedding planes, fractures (joints and fault planes) and karst surfaces developed in the exposed limestone and measured as separate entities. This is because not every joint is karst, and it looked as if the groundwater flow is choosing its own orientation in which to develop karst. A reconnaissance of mapping areas was carried out during the first few days of the mapping to quickly assess the quality and the level of weathering of the limestone outcrop. The accumulation of fracture line directions was then displayed, measured from Grid North (which is within 0° 3' East of Magnetic North in this area), by using a rose diagram to produce percentages in any given direction grouped in batches of 10° from North. The details below are the finding of each exercise carried out at, as the following:

2.1. Kuala Lumpur Limestone Formation

The limestone formation outcrops on the floor of the Klang Valley, elongated in a north-south direction with broad exposure in the north, up to 10 km. The limestone is composed almost entirely of carbonates minerals ($CaCO_3$) with few impurities, dominantly calcite but frequently containing a small percentage of magnesium (Mg). Locally dominant in certain areas is dolomitic limestone and dolomite. The types of limestone mapped in the area are described as follows, first is calcitic limestone – the recrystallized calcitic limestone ranges from white, cream, grey and less frequently, pink in colour, depending on the non-carbonates content of the formation. The rock has a granular texture with a size crystal from 0.2 mm to 1 mm and up to 5 mm adjacent to the aureole of the granite. Weathered limestone is characteristically soft/weak white sugary rock. Distinct calcite crystals are found near to fault zones. Non-carbonate impurities consisting mainly of pyrite exist as a dust and also as cubes, approximately the same size as the calcite crystals. Other forms of impurity are hematite and potassic feldspar, present at certain places, e.g. Jinjang. Second is dolomitic limestone exists as thin seams and lenses, interlayered with the calcitic limestone and commonly widely distributed in the Segambut, Jinjang, Setapak and Ampang areas. The grain size is finer than the calcitic limestone, between 0.1 mm – 0.3 mm and weathers out to form lenses of yellow honeycomb relief where the calcitic has been dissolved. The deformations which occurred between the Devonian and the Early Tertiary have largely altered the original features preserved in the bedding, including fossils and primary structures developed during the deposition.

2.2. Kinta Limestone Formation

The Kanthan limestone (Silurian-Devonian) is generally part of the Kinta Valley limestone bedrock. Kanthan rock formation is generally made up of phyllite, slate, shale, and sandstone locally prominent. Locally, Kanthan limestone at the quarry is predominantly made up of massive and thin bedded varieties, grayish white and with black carbonaceous patches/spots, fined grained limestone, frequently and in places intercalated or associated with carbonaceous (fissile) phyllite/schist. Massive, of about 4 m thick, cream to pinkish white coloured, fined grained, dolomite have been encountered running across the central part of the quarry area in N-S direction. Structurally, this limestone is often looked massive and interbedded in places as observed in many outcrops (quarry faces). The limestone beds thickness can varies from a few cm to a very massive outcrop. There are gently folded locally and occasionally interbedded with thin carbonaceous meta argillaceous layers.

2.3. Chuping Limestone Formation

Chuping Formation was named after Bukit Chuping, exposed as groups of steep-sidedkarst hills in central Perlis (Lee, 2009). This Late Early Permian to Late Triassic age rock formation consists of massive, pale coloured, finely crystalline, purely calcitic limestone (Metcalfe, 1984). The bulk of this Chuping Formation is massive and unfossiliferous, except for the base part, composed of well-bedded dark-grey shelly limestone with chert nodules in layers parallel to the bedding. This characteristics result in an extremely rugged terrain with abundant cliffs, as seen at the quarry site. Solution of the bedrock along structural discontinuity planes in the limestone hills has produced intricate patterns of caves, gorges and subsidence morphologies observed on surface. The caves can be of enormous dimensions, occupying much of the interior of a hill. Gua Badak, on the south side of Bukit Chuping, is typical and is reached through a small entrance 50 m up on the SE cliff. Structurally, the Chuping Formation has experienced few series of deformation, consists of folding and faulting. The structures were controlled by series of faulting, especially by the Kisap Thrust and accompanied by compressive forces acting primarily at E-W direction. Another deformation occurred was in relation to the intrusion of granite duringthe Late Triassic, displaced the Kisap Thrust androtated earlier structures (Mustafa, 2009).

3. Karstification of limestone formation

3.1. Kuala Lumpur Limestone Formation

Rock profile of this formation can generally be classified as heavily fractured, after (Bieniawski, 1989) and to contain numerous karst features in it. The most prominent karst feature in this section is the occurrence of two large zones of depression (Figure 1). Two different types of karst have been observed and mapped as forming in the Kampung Pandan Roundabout site, the K1 and the K2 karst. The K1 class is a fully developed karst, creates a large depression in the ground and contains weak broken weathered rock. In comparison the K2 class is a developing karst, small in size, heavily fractured and broken rock and actively developed under the influence of running water or a small underground drainage system.

Interestingly, those two fully developed K1 type share a similar pattern of dominant joint orientations, and this finding is largely based on the measurements taken from the exposed rock section close to the karst area. The larger of the two zones exists on the West Side of the box, between Ch350 and Ch370; where the karst is 20m wide and

20m deep, and, in which the base level of the cavity is at 28.85 m, approximately 12 m BGL. Surrounding the zone area is a highly fractured rock mass, with the dominant joints orientations on trends of 300°/60°NE, 60°/85°SE, 100°/80°SW and 340°/65°NE.

A continuous cross section of 20 m deep and 50 m long of exposed rock between Ch370 and Ch430 was obtained, which therefore has provided a rare profile of rock section from which to reveal the very nature of the limestone and the karst features developed in it with depth (Figure 1). In this section, two cross sections (East Side and West Side), showing the orientations of karst surfaces, are presented in comparison with the photos taken at the sites, to study the pattern and the relationship between karst and joint directions with depth.

Fig. 1. Subsurface cavity of 4 m high and 15 m long exposed at depth of 25 m below the ground level during the construction of SMART tunnel.

3.2. Kinta Limestone Formation

In Kinta Limestone Formation, the limestone generally striking in N-S direction trend, however due to the local deformation, this bedrock especially highly interbedded argillaceous black shalefrequently observed gently folded and seen formed local anticline especially in Window G (Figure 2). Local faulting and the other minor displacement also noticed in many windows. Slickenside features can be found at Window A, F, G and J, where light green clay mineral filling (Chlorite mineral bearing cement) characterized the plane face was noticed. Based on the observation at the most quarry faces, certain section shows the quarry face are parallel to the rock bedding strike that can be seen through Window B, G, E and F. A few local normal faults were observed in the rock slope which can be seen at Window F, G and J, almost striking 270° orientation, and often show slickenside features.Failure to follow the dominant joint orientations, 100°E – 270W°/60°, 45°NE - 225°SW/60°, 180°S – 360°N/40°.

Fig. 2. (a) Shows the heavily jointed rock mass of Kinta Limestone Formation; (b) Jointed and slickensided surfaces of rock mass.

3.3. Chuping Limestone Formation

Dissolved limestone features were significantly observed to be seen within all the mapped windows in Chuping Limestone Formation. These karstic features form from a progressive dissolution of the carbonate beds during wet seasons. There are three distinctive features of karstified limestone observed at site: first is the typical old-cave-in zone of karst where calcite (stalagmite and stalactite) and ferruginous brown clay minerals (clay gorge) can be seen; second is well-developed rockhead karst, creates highly irregular topography of rock below the overburden soils varying in elevation by tens of metersand containing numerous voids, many of which have collapsed and arepartially filled by brown clay minerals and the third is secondary mineralization of calcite in-filling veins, which numerously observed in each of windows mapped (Figure 3). The veins occur either as continuous, short or irregular lenses, in-filled of either joints or bedding planes and range between 1 mm and 30 cm thickness. Another obvious feature observed is the abundance of slickenside surfaces between the measured planes, and more interestingly, these surfaces are orientated in most of the times between N130° and N180°, approximately in the range of the karst orientations measured during mapping.

Fig. 3.Rugged and highly weathered rock mass of limestone outcrop to contain brown clay minerals and secondary mineralization of calcite in-filling veins of Chuping Formation.

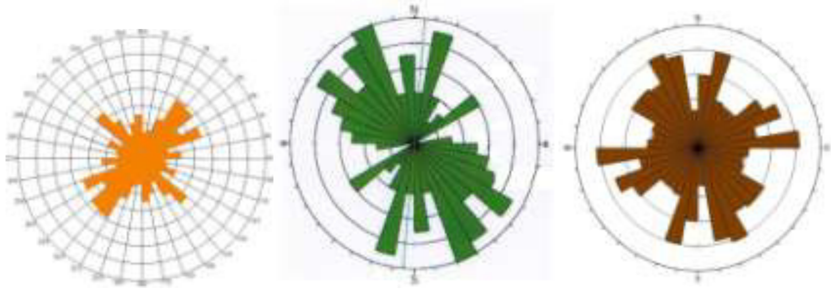
4. Results and discussion

On surface, the limestones are relatively karstic. The limestone is heavily karstified to form rugged rockhead topography near to the overburden with significant occurrences of thick calcite veins and perfectly shapes of overgrown recrystallized calcites. As for the Kuala Lumpur Limestone Formation, the karstic surfaces are consistently developed along the joint set orientated at 310°/65°NE, and at a frequency of every 2 m throughout the section.Generally, the rock is highly weathered, especially around the rockhead area, which was found to be located around 6m BGL and on the joint set orientated 310°/65°NE.

With reference to the rose diagrams (Figure 4), it can be seen that some of the karst has developed along the prominent joint orientations, but that others propagated along the least dominant joints orientations, e.g. for Ch380 – Ch420 (East side), the dominant joints orientation is aligned in the N040° direction, but the karst surfaces frequently developed in the N090° direction; the same pattern also occurs between Ch485 – Ch505 (East side), where the joints are dominantly orientated in N050° – N070° directions, but the karst is developed at the N090° direction.

In Kinta Limestone Formation, a few rock slopes especially near the top section which are at Window B, C and E were overlain by thin brownish, ferruginous red, loose top soil, disintegrated rock and loose fragmented rocks. This is mainly due to the physical weathering and alteration. This weathered top bedrock, loose soil, highly fractured and fragmented materials often exhibit more porous segment with high interstitial spaces. The tight cave features where calcite which is stalactite and stalagmite and ferruginous brown clay mineral can be seen at Window B. There are prone to collapse especially when disturbed by the blasting activities and induced by excessive water due to long raining. Discontinuity are considered as drainable porosity which provide the passage for water drainage, then it may increase the pore water pressure throughout the limestone bedrock and lower the shear strength. Because of this, there will be an exerted effective pore pressure on the rock mass aperture surface like open fractures, 43 joint set and bedding and it will reduce the effective strength of the soil and the rock mass. Oversaturated soil like clayey sand have tendency to induce gravity flow. Running water channel can be observed which are often characterized by high ferruginous clay stained at Window A and E.

In Chuping Formation, more than 1200 discontinuities were collected within 21 windows of exposed quarry faces. The contour plots show the existence of three sub-vertical joint sets and a sub-horizontal bedding plane in both hills. The plot also shows existence of high variability on orientations for the sub-vertical joint sets, range from ES, EW and NE. As expected, these orientations are in good agreement with the regional geological structure of Peninsular Malaysia, striking at range of 30° and 120°. Average dip angle of these discontinuities vary between 28° and 86°, as the sub-vertical angle of dipping (64°) shows the highest concentration of discontinuities measured. Prominent dip directions of the discontinuities were observed at N010°, N050°- N070°, N080°, N120° – N140° & N150° - N160°. The preferred orientations of karst were seen at N010, N080 and N150 – N160. High level of karstification were observed around the quarry area, of either seen as a perfectly crystal shape of calcite or recrystallized infilling calcite. The formation of karst/cavity significantly diversified the quality of rock mass, to fundamentally affect the compressive strength of rock.



(a) (b) (c)

Fig. 4.Rose diagrams of discontinuities orientations measured from three limestone formations (a) Kuala Lumpur Limestone Formation; (b) Kinta Limestone Formation; (c) Chuping Formation.

Table 1. Dominant joint orientations of three selected limestone formations.

Limestone Formation	Geological age	Dip direction	Strike/dip
Kuala Lumpur Formation	Middle Silurian to Lower-Middle Devonian	N030° to 070° and N120° to 150°	190S/60, 300NW/60 & 120SE/40
Kinta Formation	Silurian-Devonian	N300°, N130° – 140°, N270°	100E/60, 45NE/60 & 180
Chuping Formation	Late Early Permian to Late Triassic	N010°, N070° - 080°& N150° - 160°	189S/64, 99E/86, 67NE/82 & 8N/28

All three limestone formations were deposited along the west coast of Peninsular Malaysia between Middle Silurian of Kuala Lumpur Limestone Formation to Late Triassic of Chuping Formation. These limestone beds covered a vast area of Peninsular and believed to experience similar deformation periods. This is based on the joint systems recorded with the exposed outcrops of formation. All three formations agreed on the preferential orientation of dominant joints at N030° to 070°, N130° and N150° - 160° (Table 1). As predicted, these orientations are in good agreement with the regional geological structure of Peninsular Malaysia, striking at E – W and NW – SE directions. Regional alignments of Peninsular Malaysia are in between N280°, N300° – N310°, N330° – N340°

&N350^o – N360^o.These trends are part of general structures trending at NNW – SSE which later superimposed by N – S and NNE – SSW major fault zones.

5. Conclusion

All karstic surfaces are consistently developed along the joint sets orientated at limestone is strongly fractured with the dominant joint orientations.Alllimestone formations are heavily karstified to form rugged rockhead topography near to the overburden with significant occurrences of thick calcite veins and perfectly shape of overgrown recrystallized calcites. All analyses indicated that the potential failure is strongly influenced by inherited structures, like the pre-existing joint sets and bedding plane. The joints system consists of three or four orientations and often vertical and normal to the bedding planes, as seen in all sites studied.The earlier assumption of the close relationship between drainage channels and geological structures could be seen in the field by studying slickensided and karstic surfaces. Frequently found at site, mainly in the North Junction Box (Kuala Lumpur Limestone Formation), is a wet yellow coloured slickensided surface believed to have formed as a result of shear displacement and the continuous flow of running water. These fault planes are more likely to be weathered by dissolution than the more intact adjacent rock mass, and contribute to the formation of the trellis drainage system. The same condition observed in Chuping Formation, where inWindow L – O, joints, slickensided and karst surfaces are formed along the N100° and N130° directions.As well as in Kinta Limestone Formation, of grey to dark grey, interbedded to massive limestone with the presence of gouge, weathered materials (cave-karst), jointed and gently folded.

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References

1. Bieniawski, Z. T.*Engineering Rock Mechanic Classifications*. John Wiley, New York; 1989. p. 251.
2. Ericson, K., Migon, P. &Olvmo, M. Fractures and drainage in the Granite Mountainous Area, A study from Sierra Nevada, USA. *Journal Geomorphology*2004; 1-20.
3. Lee, C. P.Palaeozoic Stratigraphy in Geology of Peninsular Malaysia: Hutchison, C. S. and Tan, D. N. K, editors; 2009.
4. Metcalfe, I. The Permian-Triassic boundary in Northwest Malaya. Geological Society of Malaysia, *Warta Geologi*1984*;* **11**:111–115.
5. Mettam GR, Adams LB. How to prepare an electronic version of your article. In: Jones BS, Smith RZ, editors. *Introduction to the electronic age*. New York: E-Publishing Inc; 1999. p. 281-304.
6. Mustafa Kamal Shuib. Structures and Deformation in *Geology of Peninsular Malaysia*, Hutchison, C. S. and Tan, D. N. K, editors; 2009.
7. Mayer, L., Menichetti, M., Nesci, O. &Savelli, D. Morphotectonic approach to the drainage analysis in the North Marche region, central Italy. *Quarterly International*2003.p. 101-102, 157-167.
8. Sower, G. F. Failures in Limestones in Humid Subtropics. *Proceedings American Society Civil Engineers*1976;**101** (GT8):771–787
9. StrunkJr W, White EB. *The elements of style*. 3rd ed. New York: Macmillan; 1979.
10. Van der Geer J, Hanraads JAJ, Lupton RA. The art of writing a scientific article. *J SciCommun* 2000;**163**:51-9.
11. Waltham, A. C. & Fookes, P. G. Engineering classification of karst ground conditions. *Quarterly Journal of Engineering Geology and Hydrogeology* 2003;**36**:101-118
12. Waltham, T., Bell, F., Culshaw, M.*Sinkholes and Subsidence, Karst and Cavernous Rocks in Engineering and Construction.* Praxis Publishing; 2005.p. 381.